CLIMATE SCENARIOS FOR MID CENTURY AND SOME PRELIMINARY PERSPECTIVES ON ENGINEERING IMPLICATIONS

Charlton, R., Sweeney, J., Fealy, R., Murphy, C., and Moore, S.
Department of Geography, National University of Ireland, Maynooth

1. INTRODUCTION

The UN Framework Convention on Climate Change committed developed countries to reduce emissions of greenhouse gases to 1990 levels by the end of 2000. The ultimate objective of this process was to achieve the stabilisation of greenhouse gas concentrations "at a level that would prevent dangerous anthropogenic interference with the climate system". It was also considered desirable that such a level "should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change." These aspirations have not been realised. More recently, the Kyoto Protocol of 1997, which aimed to achieve a 5.2% reduction in emissions of six key greenhouse gases by 2012, has also been rejected by some leading industrial countries. Nonetheless it is currently an objective of EU policy that an emission reduction target of 8% be achieved by the target date. These commitments include an undertaking that demonstrable progress must be made by 2005. As part of a burden-sharing arrangement with EU member states, Ireland has been set a target of restricting the growth of emissions to less than 13% during the reference period 1990 to 2008-12. This target is unlikely to be met in the absence of radical measures and the permitted increase in emissions was probably passed by 2000 with an eventual rise of over 37% likely to occur under a 'business as usual' assumption (Stapleton et al, 2000). The National Climate Change Strategy, published in October 2000, provides a strategic framework to tackle the emission reduction of 13.1Mt CO_2 equivalent required to comply with the Kyoto Protocol (Department of the Environment and Local Government, 2000). It is however a long way away from successful implementation.

The need for radical measures has been demonstrated at a global scale by the publication of successive Intergovernmental Panel on Climate Change Assessment Reports in 1990, 1995 and 2001. These have asserted with increasing confidence that a discernible anthropogenic impact on global climate can now be detected. Growing observational evidence and the increasing ability of computer models of the global circulation to simulate the effects of atmospheric modification as a result of escalating greenhouse gas concentrations provides the main bases for such conclusions. As such, these models provide a means of either projecting the future course of global climate in the absence of effective mitigation measures or assessing the effectiveness of particular measures in deflecting trends away from a 'business as usual scenario'.

Future changes in Irish climate are likely to have significant impacts on its hydrology. These may influence the annual and seasonal availability of water resources, with particular impacts being felt in terms of water resource management, water quality management and approaches to coping with flood/drought hazards.

2 DOWNSCALING OF GLOBAL CLIMATE MODELS

To begin the process of generating future climate scenarios it is first necessary to derive an Irish baseline climatology for the present to calibrate future changes. Monthly data for 570 stations for precipitation and 70 stations for maximum/minimum temperature were employed for this. For both temperature and precipitation, some stations over 700m O.D. were included. In order to derive climatological values for the areas intervening between the station locations, a regression model was employed similar to that of Goodale *et al*, (1998). A Digital Elevation Model (DEM) of Ireland at a resolution of approximately 1km^2 was used to provide height data.

The relatively coarse resolution (typically grid sizes >2.5^o) of Global Climate Model (GCM) output limits their utility for assessing the impacts of climate change, many of which require analysis at sub grid scale. Obtaining regional scenarios involves translating the GCM output to finer spatial scales, a technique known as downscaling. One of the most widespread approaches has been the incorporation of mesoscale predictor variables in an empirical statistical technique that establishes linkages between the gcm output and surface observations. This statistical downscaling technique is based on the assumption that GCMs simulate mesoscale aspects of climate better than surface variables such as temperature and pressure (Palutikof, 1997). The method involves firstly establishing relationships between conservatively changing upper air variables, such as geopotential temperatures and heights and local surface observations. Over a training period, the relationship between these sets of variables is established and assumed to be robust in a changing climate situation. Since the same mesoscale variables also are outputs of the GCM, the local surface variables in a changed climate situation may then be estimated via the transfer function. Downscaling is done for individual point locations both for the baseline and future runs of the model and the differences are applied to the observational data to provide a climate change scenario (Wilby and Wigley, 1997).

Daily output from the Hadley Centre GCM for the grid cell specific to Ireland was then obtained for the period 1960-2100. The particular run concerned (HadCM3GGa1) is a ‘middle of the road’ scenario which produces global temperature increases of approximately 3.5^{o}C by 2100.

The first step in downscaling is to match surface observational data to observed mesoscale data which also exists as output from the GCM. The mesoscale variables employed consisted of upper air re-analysis data for the period 1961-90 and included the height of the 500hPa surface, the 500-850hPa thickness, mean sea level pressure, specific and relative humidity. This mesoscale re-analysis data was then regressed on local surface variables, such as temperature and precipitation, for the same period from a large number of locations/stations within Ireland to establish transfer functions unique to each point and for each month individually.

The second step entails extracting the same key variables from the HadCM3 output, for time slices in the future, which are then used as input to the transfer functions to predict the future surface conditions at the same points. Statistical downscaling was conducted for 250 stations for precipitation, and 60 for temperature. Polynomial regression, as used in deriving the baseline climatology, was then again employed to redistribute the downscaled values across the domain at a resolution of 10 km^{2}. Downscaling was undertaken for three periods: 1961-90, 2041-70 and 2061-80. The modelled differences between the 1961-90 and later runs were were then added to the baseline climatology. It is the relative difference between modelled time slices that are used as oppose to absolute values in order to account for certain biases which may occur in the modelled data. Scenarios of change for approximately 2055 and 2075 by comparison to the 1961-90 averages could thus be constructed.

Validation of the transfer functions was performed using an independent dataset from 1991-97. In general temperature verification was good, particularly for summer maxima. Minimum temperatures were predicted well for all seasons by the technique. As expected, downscaling precipitation was found to be less accurate at all times of the year.

A sample of the output for 2055 is shown in Figures 1 and 2. A general increase of approximately 1.5^{o}C in mean January temperatures is. By mid century winters in Northern Ireland and in the north Midlands will be similar to those of Cork/Kerry during the 1961-90 period. Mean July temperatures average 16.5-18^{o}C as far north as coastal Co. Antrim and Derry by mid century. General increases of approximately 2^{o}C are apparent with highest values to be found inland away from north and west facing coasts. Combined with reduced summer precipitation amounts, the principal impact of this is likely to manifest itself in increased evapotranspiration and increased occurrence of soil moisture deficits and drought stress.

It must be stressed that precipitation scenarios are inherently less reliable than temperature given the uncertainties of GCMs in this area. This has been a feature of many downscaling studies (Burger,1996; Wilby *et al*, 1998). However, winter increases in precipitation are likely to be observed particularly for the north west, while summer, reductions in rainfall across eastern and central Ireland of up to 40% are projected. Such decreases, if realised, would clearly have profound implications for water resource management.

3. PROJECTING FUTURE RUNOFF

Although the grid squares used for climate scenario generation do not represent actual catchments, they do allow changing spatial patterns of annual and seasonal runoff to be explored. The hydrological simulation model HYSIM (Manley, 1978, 1993) was used to investigate the hydrological changes likely to be associated with the climatic changes projected. This is a versatile model that has previously been used in examining the effects of climate change on water resources (Pilling and Jones, 1999) and is the standard rainfall-runoff model used by the UK Environment Agency. HYSIM uses rainfall and potential evaporation data to simulate river flow and uses parameters for hydrology and hydraulics that define the river basin and channels in a realistic way. This means that the model is more likely to perform well under climatic conditions more extreme than those for the calibration period. HYSIM is flexible in its data requirements and provides a range of output which includes simulated streamflow, simulated storage in each conceptual reservoir (e.g. upper and lower soil moisture, groundwater) and simulated transfers between these reservoirs.

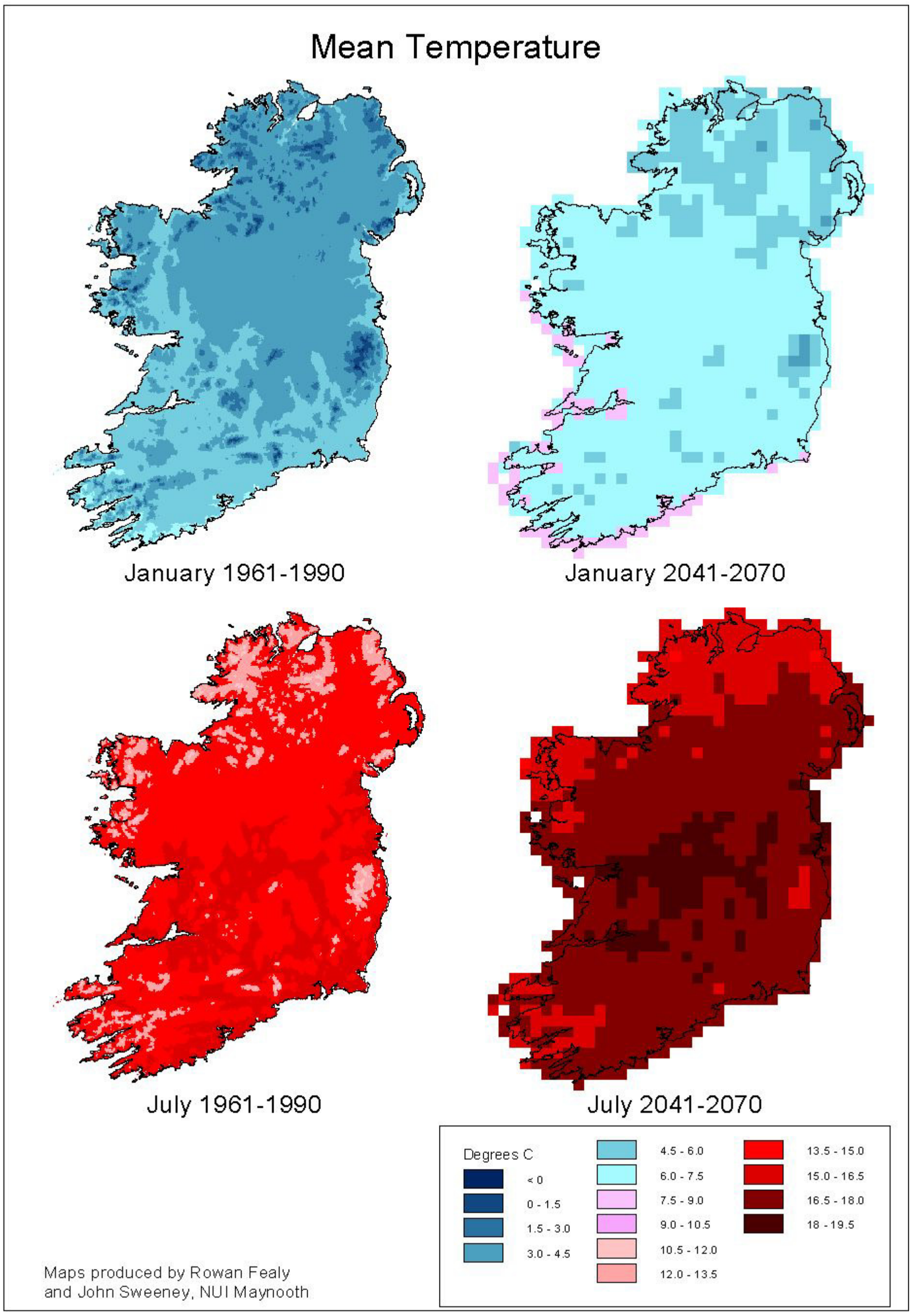

Figure 1: Downscaled mean temperature scenarios for Ireland for the period 2041-70 at a resolution of $10km^2$. This approximates to the period around 2055.

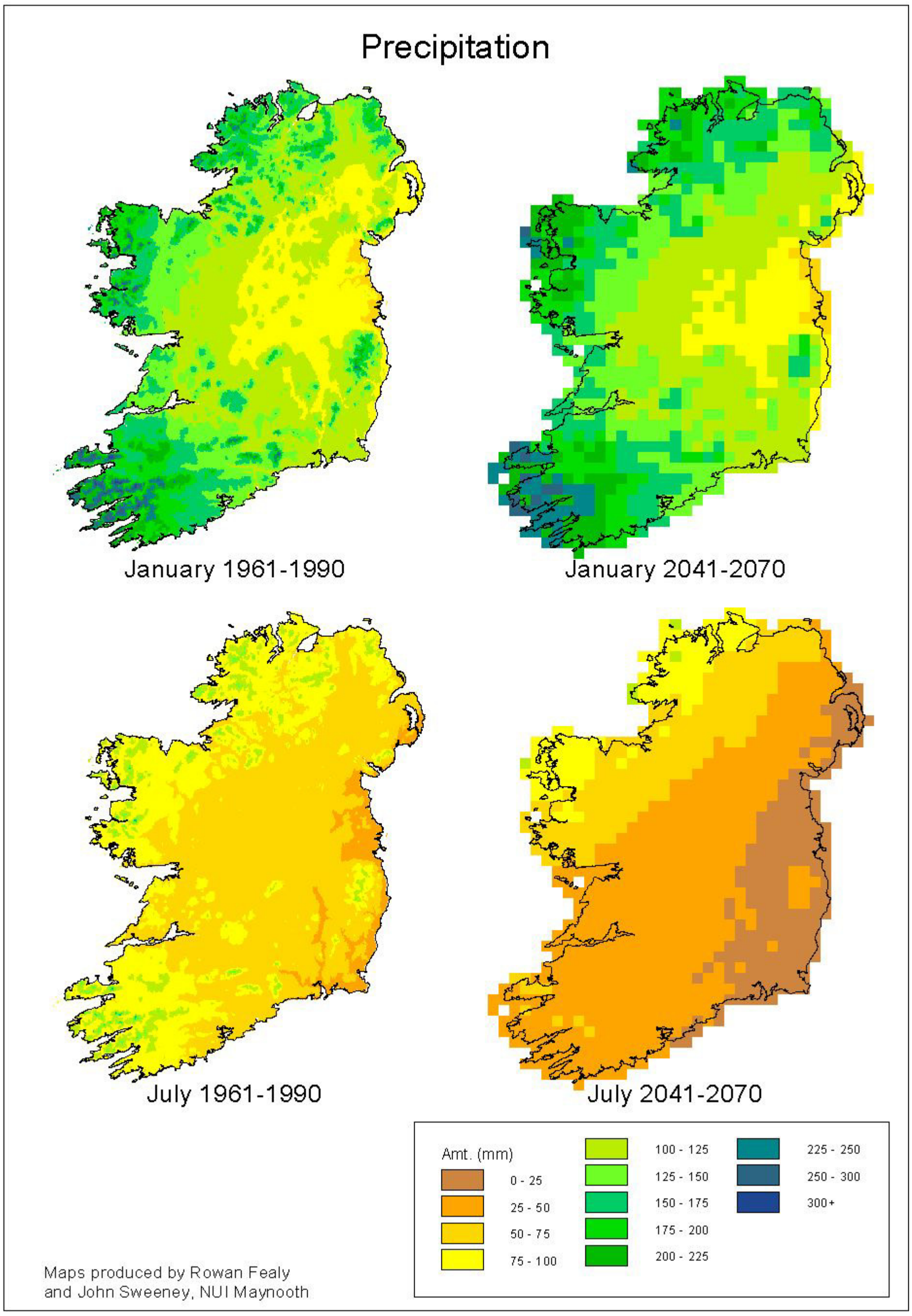

Figure 2.: Downscaled precipitation scenarios for Ireland for the period 2041-70 at a resolution of $10km^2$. This approximates to the period around 2055.

HYSIM has been designed to enable quantitative values for the soil hydrological parameters to be derived using soil survey data (Manley, 1993). These values are assigned on the basis of the soil textural characteristic which is determined from the relative proportions of sand, silt and clay sized particles.To provide this input, soil data for each $10km^2$ grid square was derived from a digitised 1:575 000 map and the 44 soil associations for Ireland were reclassified into 11 soil textural groups, according to the relative proportions of sand, silt and clay for typical depth profiles for each soil association. A soil texture was derived for each soil horizon and from this an overall soil texture was allocated for each soil association. Two additional hydrological classes were included to represent areas of blanket bog and raised bog. These parameter values were not assigned on the basis of texture but by using the field and laboratory observations made by Galvin (1976) and Feehan and O'Donovan (1996).

HYSIM also requires vegetation and land use data, including the rooting depth of vegetation, impermeable areas, permeability of the soil surface and the rainfall intercepted by different types of vegetation. Estimates for these parameters were obtained using CORINE data (O'Sullivan, 1994). CORINE classifies land use into 44 categories, although many of these are not relevant to Ireland (e.g. vineyards, olive groves and glaciers) or occur over such a small area that they did not occur on the 10x10 km grid. As a result eleven land use classes exist on the 10x10 km grid map.

Although groundwater parameters would also normally be required for the model, it was not feasible to derive recession coefficients for every catchment and in any event a sensitivity analysis suggested this was less critical over the relatively long time periods being modelled. A simpler approach was adopted by assigning each square with a groundwater reservoir and using an 'average' value for the recession coefficient suggested by Manley (1993).

For each grid square, monthly mean values for precipitation and evapotranspiration were used to drive three sets of hydrological model runs, using a hydrological simulation period of one year. Simulations were carried out for the baseline (1961-90) climatology and downscaled future climate scenarios for the 2041-70 and 2061-90 periods. Aggregation of grid squares was used to examine individual catchments in more detail.

Validation was carried out on a number of selected catchments. Table 1 shows the annual observed and predicted effective runoff for these under baseline conditions. From this it can be seen that the Feale, Slaney and Brosna all fall within ±10% of the observed values, with the percentage error for the Suir being just over 10%. However the predicted runoff is under-estimated by over 18% for the Shannon and almost 23% for the Bonet. The under-prediction of runoff for the Shannon and Bonet, which both drain upland areas, was observed for all seasons and could be due to an under-prediction of precipitation produced by the gridded climatology; the altitude of individual summits would have been suppressed as a result of the interpolation process.

Table 1: Observed and modelled baseline runoff for selected catchments for 1961-90

Effective runoff	Feale	Suir	Slaney	Shannon	Brosna	Bonet
Predicted (mm)	1059	618	567	646	476	950
Observed (mm)	1071	697	565	788	442	1232
% error	-1.1	-11.4	0.2	-18.0	7.7	-22.7

Figure 3 shows the projected percentage change in runoff for 2041-70 relative to the baseline simulation for the annual, winter and summer periods. Annually, an overall decrease in runoff is predicted for most of Ireland. West of the Shannon an increase in winter runoff is seen while to the east runoff decreases are apparent. A country-wide decrease in runoff during the summer is projected. For the more severely affected eastern parts this reduction exceeds 30%.

Changes in runoff for the validation catchments are shown in Table 2. The predicted runoff for 2041-70 was compared with the predicted runoff from the baseline period rather than the observed runoff. The greatest change, an annual reduction in effective runoff of approximately 25% of the baseline flow, is observed for the Slaney. The area drained by this river is in the south east of the country where the some of greatest reductions in predicted runoff occur. The predictions indicate that the Brosna and Suir will experience an annual reduction of between 10 and 20% and the Shannon, Feale and Bonet less than 10%.

Table 2 Percentage change in effective runoff for the 2041-70 scenario relative to baseline simulation

2041 – 2070	**Annual**	**Winter**	**Summer**
Feale	-7.2	3.5	-31.2
Suir	-15.9	-3.9	-22.6
Slaney	-24.9	-11.4	-31.5
Shannon*	-9.0	4.2	-29.1
Brosna	-18.0	-3.5	-28.1
Bonet*	-4.1	7.3	-19.9

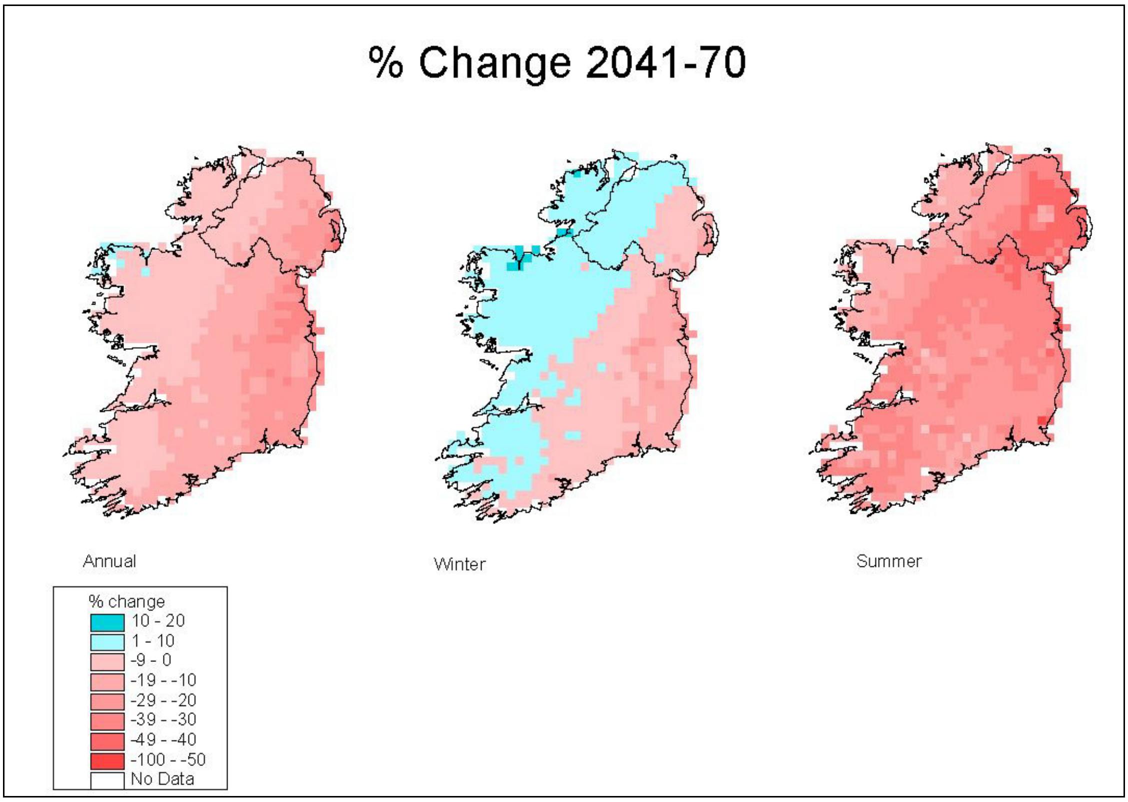

Figure 3: Change in annual and seasonal runoff for 2061-2090 as a percentage of 1961-90 baseline

Clearly it is in some of the areas where the greatest percentage change is predicted that current water demand is highest and most likely to increase in future. These areas include the Dublin and the Mid East regions. A large proportion of the water supplied to the Greater Dublin Area is abstracted from rivers draining the Wicklow Mountains, including the upper Liffey. Any reduction in rainfall in the winter months to recharge stores within these catchments could exacerbate problems caused by reduced summer rainfall and increased evaporation rates. Reduced storage would mean that less water would be available during the drier months to sustain low flows and could result in water shortages. Increased water quality problems may also arise, as a result of the reductions in runoff and the likely increase in the frequency and duration of low flows. It is essential that more conservative effluent consent criteria be incorporated into the licensing process to ensure that water quality is maintained.

4. CONCLUSIONS

The principal impacts indicated by the model results are:

- Reductions in annual runoff by mid century will be most marked in the east and south-east. A slight increase may be observed over a limited area in the north-west.
- Winter runoff is predicted to increase in the west with the magnitude and frequency of individual flood events increasing.
- All areas will experience a decrease in summer runoff, with the greatest reductions in the east of the country. It is likely that the frequency and duration of low flows will increase in many areas.
- Long term deficits in soil moisture, aquifers, lakes and reservoirs are likely to develop.
- A need to employ other models and other methodologies to examine the validity of the conclusions reached is apparent, though should not prevent precautionary action being taken at present.

5. ACKNOWLEDGEMENTS

This research forms part of the Environmental RTDI Programme 2000-2006, developed and managed by the Environmental Protection Agency (Ireland) and funded by the National Development Programme.

6. REFERENCES

Burger, G. (1996) Expanded downscaling for generating local weather scenarios, Climate Research 7, 111-128.

Department of the Environment and Local Government (2000) National Climate Change Strategy Ireland. (Dublin, Stationery Office).

Feehan, J., O'Donovan, G., (1996) The Bogs of Ireland: An introduction to the natural, cultural and industrial heritage of Irish peatlands. Environmental Institute, University College Dublin, Dublin.

Galvin, L.F. (1976) Physical properties of Irish peats. Irish Journal of Agricultural Research 15, 207-221.

Goodale, C., Aber, J., and Ollinger, S. (1998) Mapping monthly precipitation, temperature and solar radiation for Ireland with polynomial regression and a digital elevation model, Climate Research 10, 35-48.

Manley, R.E. (1978) Simulation of flows in ungauged basins, Hydrological Sciences. Bulletin 23, 85-101.

Manley (1993) HYSIM Reference Manual. R.E. Manley Consultancy, Cambridge. 63pp.

O'Sullivan, G. (ed.) (1994) CORINE Land Cover Project (Ireland). Project Report, December 1994. Ordnance Survey of Ireland and Ordnance Survey of Northern Ireland Belfast, Dublin.

Palutikof, J.P., Winkler, J.A., Goodess, C.M. and Andresen, J.A. (1997) The simulation of daily temperature time series from GCM output. Part 1: comparison of model data with observations, Journal of Climate 12, 1480-9.

Pilling, C. and Jones, J.A.A., (1999) High resolution climate change scenarios: Implications for British runoff, Hydrological Processes 13, 2877-2895.

Stapleton, L. (2000) Ireland's Environment: a Millennium Report. Environmental Protection Agency, Wexford.

Wilby, R. and Wigley, T.M.L. (1997) Downscaling general circulation model output: a review of methods and limitations, Progress in Physical Geography 21, 530-48.

Wilby, R.L., Hassan, H. and Hanaki, K. (1998) Statistical downscaling of hydrometeorological variables using general circulation model output, Journal of Hydrology 205, 1-19.